1975-09

# Design of a repeater-jammer experiment for a monopulse radar

Duncan, Michael Joseph

Monterey, California; Naval Postgraduate School

DESIGN OF A REPEATER-JAMMER EXPERIMENT FOR A MONOPULSE RADAR.

Michael Joseph Duncan

NAVAL POSTGRADUATE SCHOOL
Monterey, California

# THESIS

DESIGN OF A REPEATER-JAMMER EXPERIMENT
FOR
A MONOPULSE RADAR

by

Michael Joseph Duncan

September 1975

Thesis Advisor: David B. Hoisington

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle) Design of a Repeater-Jammer Experiment for A Monopulse Radar | | 5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; (September 1975) |
| | | 6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s) Michael Joseph Duncan | | 8. CONTRACT OR GRANT NUMBER(s) |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS |
| 11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940 | | 12. REPORT DATE September 1975 |
| | | 13. NUMBER OF PAGES 41 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Naval Postgraduate School Monterey, California 93940 | | 15. SECURITY CLASS. (of this report) Unclassified |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Jamming
Monopulse radar
Interferometer

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A current problem of interest in the Electronic Counter-Measures field is the deception of monopulse type radars. The operational evaluation of any deception device requires that some preliminary work be accomplished in order to establish what electronic devices are most suitable for the job and what specific parameters these devices must meet. This paper investigates the feasibility of installing a monopulse deception repeater on board

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
(Page 1) S/N 0102-014-6601 |

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

a steel-hulled ship, the RV ACANIA. The specific parameters investigated are the peak power required for deception and the electronic gain required of the repeater loops. Prior to calculation of these parameters it was necessary to determine the radar cross section of the ship test platform and to measure the antenna isolation to insure its adequacy to prevent destructive feedback of the repeater loops. Successful completion of these experiments enabled one to specify that a traveling wave tube amplifier with a power output of 60 dBM and a gain of 53 dB would be an appropriate device for the loop amplifiers.

Design of a Repeater-Jammer Experiment
for
A Monopulse Radar

by

Michael Joseph Duncan
Lieutenant, United States Navy
B.S., United States Naval Academy, 1968

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
September 1975

## ABSTRACT

A current problem of interest in the Electronic Counter-Measures field is the deception of monopulse type radars. The operational evaluation of any deception device requires that some preliminary work be accomplished in order to establish what electronic devices are most suitable for the job and what specific parameters these devices must meet. This paper investigates the feasibility of installing a monopulse deception repeater on board a steel-hulled ship, the RV ACANIA. The specific parameters investigated are the peak power required for deception and the electronic gain required of the repeater loops. Prior to calculation of these parameters it was necessary to determine the radar cross section of the ship test platform and to measure the antenna isolation to insure its adequacy to prevent destructive feedback of the repeater loops. Successful completion of these experiments enable one to specify that a traveling wave tube amplifier with a power output of 60 dBM and a gain of 53 dB would be an appropriate device for the loop amplifiers.

TABLE OF CONTENTS

# I. INTRODUCTION

## A. THEORY OF OPERATION

Electronic countermeasures against monopulse tracking radars present a more difficult problem than more conventional tracking radars such as conical scan. Most current deception techniques depend heavily on the utilization of the scanning frequency to be effective. When knowledge of this frequency is denied by scanning on the receiving antenna only, one must then depend on swept type deception and on intelligence data to estimate the scan frequency. With a monopulse radar there is no scan, and conventional deception techniques are of little value with respect to angle deception.

One possible means of providing some degree of angle deception against a monopulse radar might be the use of an interferometer pair of repeaters to produce a diffraction pattern at the victim radar's antenna. This would produce an effect similar to that produced when tracking a complex target which can be modeled by a number of independent scattering elements as described in ref. 1. The technique has been applied against a monopulse radar, with some success, under essentially laboratory conditions. This paper presents certain basic requirements which must be met in order to operationally evaluate an interferometer system under field conditions.

## B. A PRACTICAL SYSTEM

The only monopulse radar available at this facility for test purposes is a Nike Ajax radar. It is an ideal test

radar in this case since its power output would not require excessively powerful amplifiers in the two repeater loops. In addition, the radar is equipped with a boresighted TV camera on the antenna pedestal which could provide qualitative data on the effectiveness of the ECM technique.

Initially, installation of the repeater pair on a small aircraft was considered since the technique was developed with the surface-to-air missile problem in mind. In addition, the small radar cross section of the aircraft would not require much jammer power to be effective against the test radar. Power requirements for even moderate power TWT's were well beyond the capabilities of the alternator power supply system in the available aircraft, effectively eliminating it from consideration. A second option available for a test target was this facility's research ship, the RV ACANIA. Power considerations were much less of a problem and the prime relevance of the problem was now shifted to the anti-ship missile defense problem with obvious implications for air defense.

The ACANIA is a steel-hulled, 120 foot by 21 foot vessel utilized primarily for oceanographic research. Her radar cross section was unknown, and one of the first important considerations was to obtain this data needed to estimate the repeater loop gain and the peak power required of the TWT amplifiers. In addition it was not known if the Nike Ajax would track a surface target at grazing angles since it was designed as a ground-to-air missile system. A preliminary

tracking exercise demonstrated that the surface target could be tracked and further efforts determined the radar cross section.

Repeater loop antennas were chosen from several available X-band horns. A pair of horns from an APG-30 radar were chosen for their sealed construction and because there were four of them available with nearly identical gain and pattern characteristics. Experiments were then conducted with one pair to determine if their actual characteristics were as nearly identical as the data available indicated. In addition, the isolation between the antenna pair was measured both in simulated free space and on board the ACANIA to make sure that loop feedback would not present a problem.

With the data from these experiments in hand it was then possible to calculate the gain and peak power required from the loop amplifiers and to select amplifiers to meet these requirements.

# II. RADAR CROSS SECTION OF THE ACANIA

## A. NATURE OF THE PROBLEM

### 1. General Theory

In order to make a selection of a power amplifier for the repeater loops it is necessary to have a reasonable estimate of the target's radar cross section. Once this parameter is known the loop gain required of the amplifier may be found by applying the following equation from ref. 2.

$$G_e = 4\pi C\sigma/\lambda^2 G_t G_r \qquad (1)$$

Where:

$G_e$ = Loop gain required

$\sigma$ = ACANIA radar cross section

$G_r$ = Gain of jammer receiving antenna

$G_t$ = Gain of jammer transmitting antenna

$C$ = Jammer to signal return ratio

$\lambda$ = Wavelength

The radar cross section of an unknown target may be found by comparing its echo with that of a sphere of known dimensions suspended from a balloon. The radar cross section of a sphere which has a diameter much greater than a wavelength, is given by $\sigma = \pi r^2$ in ref. 3 and may be readily calculated. One form of the free-space radar range equation is:

$$P_r = PG^2\lambda^2\sigma/4\pi R^4 \qquad (2)$$

Where:

$P_r$ = Echo power returned to the receiver

$P$ = Transmitter power

$G$ = Gain of the radar antenna

$\lambda$ = Wavelength

$\sigma$ = Radar cross section of target

$R$ = Range to the target

It follows from equation (2) that if the power received from the ACANIA is equal in magnitude to that received from the calibration sphere for equal transmitter power in the two cases, then:

$$\sigma_{ACANIA} = \sigma_{SPHERE} (R_{ACANIA} / R_{SPHERE})^4 \tag{3}$$

The above equation gives the effective cross section of the ship. The free space value of the cross section may be larger or smaller than this value since the power received from the ship may be increased or decreased by reflections from the water surface. The effective cross section would have to be remeasured if the elevation of the radar were to be changed by a significant amount. The range of the sphere and of the unknown target may be determined by radar measurement. The remaining terms in the radar equation are the same irrespective of the target, provided the measurements are carried out in a relatively short time period. The AGC voltage in the azimuth channel was selected as a measure of the received signal strength.

It is assumed that when the AGC voltage obtained from the target equals that from the sphere, the signal strengths

are equal. One difficulty with this assumption is that the AGC circuit has a time constant of about .003 seconds, and the AGC voltage is determined by a weighted average of the strength of the pulses received over several time constants. While the signal strength from the sphere varies only slowly, the signal strength from the ACANIA may vary rapidly due to scintillation as the target aspect changes. Thus this method gives a weighted average cross section for a particular aspect. An average value of AGC voltage was used in the calculations, since there were considerable fluctuations in the recorded data, to determine an average cross section. AGC voltage fluctuations were especially noticeable when the broadside aspect was presented. Maximum and minimum cross sections were also determined for the stern aspect. This is the aspect that appears to be optimum for use in the dynamic tests of the countermeasure.

2. Glint and Image Problems

Due to the location of the Nike Ajax radar utilized in the radar cross section experiment, problems were expected in tracking a surface target. The radar antenna was sited on top of a building approximately 135 feet above sea level. At a range of 6000 yards this gave a look-down angle of approximately one half of one degree. Therefore, it was expected that the image of the target would also be seen by the radar and make accurate tracking in the elevation channel impossible. This particular installation of the Nike Ajax was equipped with a boresighted TV camera which allowed the operator to observe, qualitatively, the tracking accuracy.

It was found that the radar would not track in elevation at low angles, so the operator was required to manually position the antenna either from the TV picture or by use of the elevation error meter reading. This appeared to satisfactorily solve the image problem.

In the azimuth channel, errors were expected to occur from the complex nature of the target and from reflections off of the sea. As discussed in ref. 1, Chapter 5.5, angular errors may occur both from amplitude fluctuations of the received signal and from changes in the target aspect. For a monopulse type radar, which obtains its angular information on a pulse-to-pulse basis, amplitude fluctuations are not important. However, since this experiment dealt with the measurement of the AGC voltage, and since the AGC voltage is derived from an average of several pulses, amplitude fluctuations due to target aspect changes are very important.

Considerable angle fluctuation or target glint was also observable qualitatively on the boresighted TV system. The apparent radar reflecting center appeared to wander in a random fashion and spent about fifteen percent of the time outside the physical limits of the target. This effect was most pronounced on the broadside aspect as expected, since more scattering elements are visible in the radar beam.

In addition to the glint and image problems, signal-to-noise variations might have affected the results of this experiment. Noise peaks would appear on the operators scope both outside and within the range gate at random intervals, sometimes exceeding the strength of the received signal from

the target. Peaks of that order were relatively rare within the range gate, however, and were considered to be statistically insignificant in view of the strong return from the ship and the infrequent occurrence of large noise pulses. The noise peaks were probably due to specular reflection from the surface of the sea, since waves on the order of two feet were present.

## B. EXPERIMENTAL PROCEDURE

Calibration of the Nike Ajax radar was accomplished prior to tracking the surface target by acquiring and tracking a six inch diameter sphere suspended from a helium-filled balloon. The cross section of the sphere, which for a test frequency of 9 GHZ falls in the so-called optical region, is given by $\pi a^2$ where a is the radius of the sphere [ref. 3]. In this case the cross section was 0.0182 square meters. The sphere was acquired at a range of 1200 yards and tracked to a range in excess of 20,000 yard. The AGC voltage was recorded on a strip-chart recorder scaled for 2.5 volts full scale and 50 millivolts per division. The tape speed was one millimeter per second and range marks were placed on the tape manually as read from the dials on the operators console. This did not yield a continuous read out of range but gave sufficient accuracy when data points were selected to fall at known ranges. Range change was not rapid, on the order of 4.5 yards per second, so that little error was introduced in the manual recording of this variable.

Immediately following the calibration run with the sphere, the ACANIA was acquired and tracked inbound from a range of 12000 yards. At 6250 yards a starboard turn was commenced presenting a port broadside aspect at 6000 yards. A 360 degree turn was completed. A starboard aspect was presented at 5700 yards. The ACANIA then proceeded inbound showing a bow aspect with a good data point occurring at 5500 yeards. The aspect of the vessel was based on sightings taken on board the ACANIA and reported to the data recorders via a VHF two-way communication link.

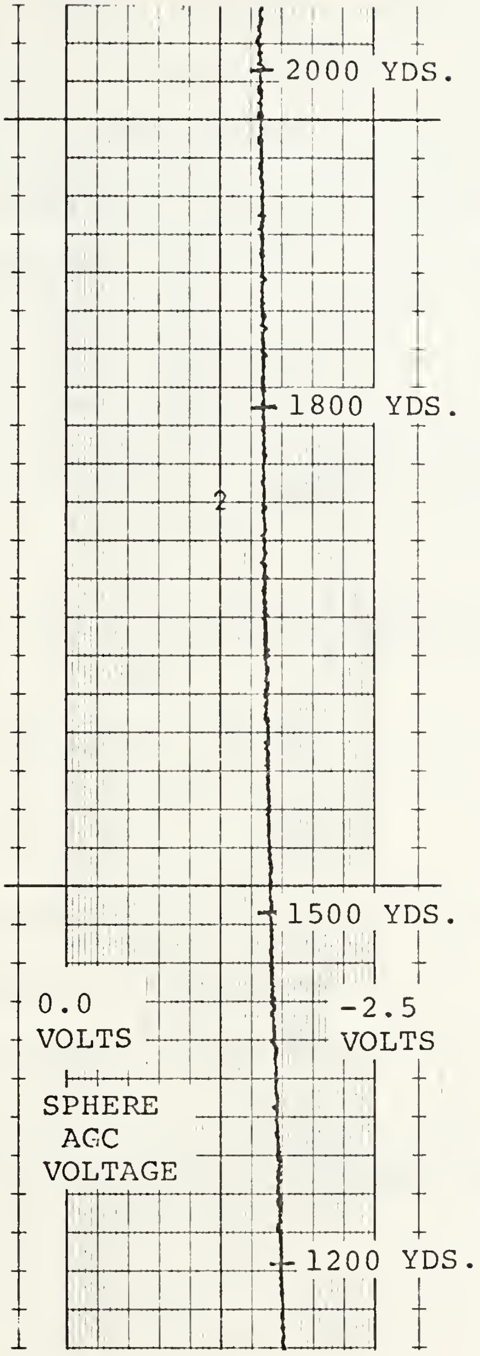
Upon completion of the experiment it was almost immediately apparent that it was necessary to find some method for extending the data obtained during the calibration run on the sphere. Almost all AGC voltages for the ACANIA were in excess of -2.0 volts, while the highest AGC voltage available from the sphere track was -1.75 volts. Once exception was the stern aspect measured at 10,100 yards which gave an average AGC voltage of -1.75 volts. The easiest solution would have been to obtain a sphere of larger diameter and repeat the experiment, but due to time constraints a signal substitution method was employed to simulate a larger sphere. A signal was introduced into the main IF strip of the receiver while recording the AGC voltage as in the previous work. Attenuation was then added until the same AGC voltage was recorded that occurred in the sphere tracking data at 1200 yards. Attenuation was then removed allowing the power received and the AGC voltage to increase until specific AGC voltages were reached which corresponded

to data recorded in the ship tracking exercise. The amount of attenuation change in dB corresponded to the increase in radar cross section of the sphere necessary to produce a specific AGC voltage change. A specific example of this method is included in the data section of this paper for futher clarification. Unfortunately it was not possible to take this data on the same day that the radar cross section measurements were made. This gives a possible source for error for the bow and broadside cross sections which will be discussed in the conclusion section.

C. PRESENTATION OF DATA

Sample data from the sphere tracking run is presented in figure 1. Note that the AGC voltage shows little fluctuation. This is to be expected from a very nearly symmetrical target. Note also that the maximum negative voltage achieved in the automatic mode was about -1.75 volts at 1200 yards.

Excerpts from the ship tracking run are presented in figures 2 and 3 at specific points of interest. Fluctuations in power received, as measured by the change in AGC voltage, are on the order of $\pm 12$ dB for a bow aspect and $\pm 40$ dB for broadside aspect. The points selected for radar cross section computation were bow aspect at 5500 yards, starboard beam at 5700 yards, port aspect at 6000 yards and stern aspect at 10,100 yards. The signal substitution data for these points is contained in figure 4. Values of AGC voltage which occurred approximately 50 per cent of the time were selected at these points and the increase in reflected power over that reflected



2000 YDS.
1800 YDS.
2
1500 YDS.
0.0
VOLTS
-2.5
VOLTS
SPHERE
AGC
VOLTAGE
1200 YDS.


FIGURE 1

from the 6 inch diameter sphere at 1200 yards was measured by signal insertion. Since the power increase is directly proportional to the radar cross section, the rest of the factors in the radar range equation being constant, the change in reflected power is also the increase in cross section required. An example follows for a bow aspect at 5500 yards:

From figure 2, AGC voltage = -2.05 volts (average value)

From figure 4, change in power or $\Delta\ \sigma$ = 36 dB - 16 dB = 20 dB

$$\sigma_{BOW}\ (dBm^2) = 10\ LOG \left[ \sigma_{SPHERE} (m^2) \left( \frac{R_{SHIP}}{R_{SPHERE}} \right)^4 \right] + \Delta\sigma (dB)$$

$$\sigma_{BOW} = 10\ LOG \left[ .0182 (m^2) \left( \frac{5500\ yds}{1200\ yds} \right)^4 \right] + 20\ dB$$

$$\sigma_{BOW} = 9.05\ dBm^2 + 20\ dB$$

$$\sigma_{BOW} = 29.05\ dBm^2 \approx 800 m^2 \qquad \text{(average)}$$

Similar computations for the port and starboard beam aspects yield average radar cross sections on the order of 40 $dBm^2$. The stern aspect average cross section was calculated directly from the AGC recording at 1200 yards giving a value of 20 $dBm^2$. Maximum and minimum values of the stern aspect ranged from 28 $dBm^2$ to 14 $dBm^2$.

D. CONCLUSIONS

There are few sources of data available for comparison of ship radar cross sections with the radar cross section measured in this experiment especially when one consideres the fact that physical dimensions are not the sole determining factor. A series of radar cross section experiments, conducted at NRL,

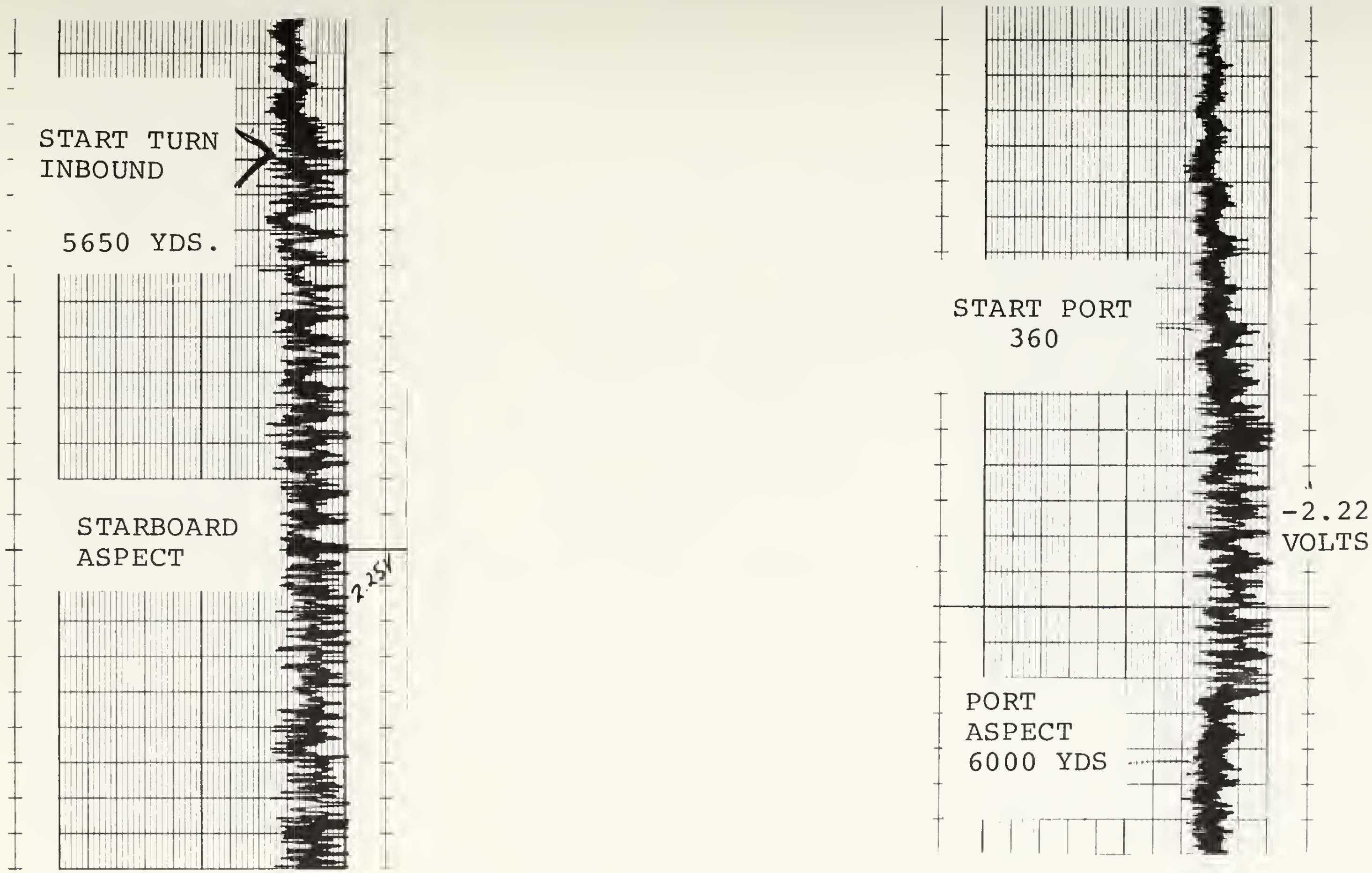

START TURN
INBOUND
5650 YDS.
STARBOARD
ASPECT
2.25V
START PORT
360
-2.22
VOLTS
PORT
ASPECT
6000 YDS

FIGURE 2

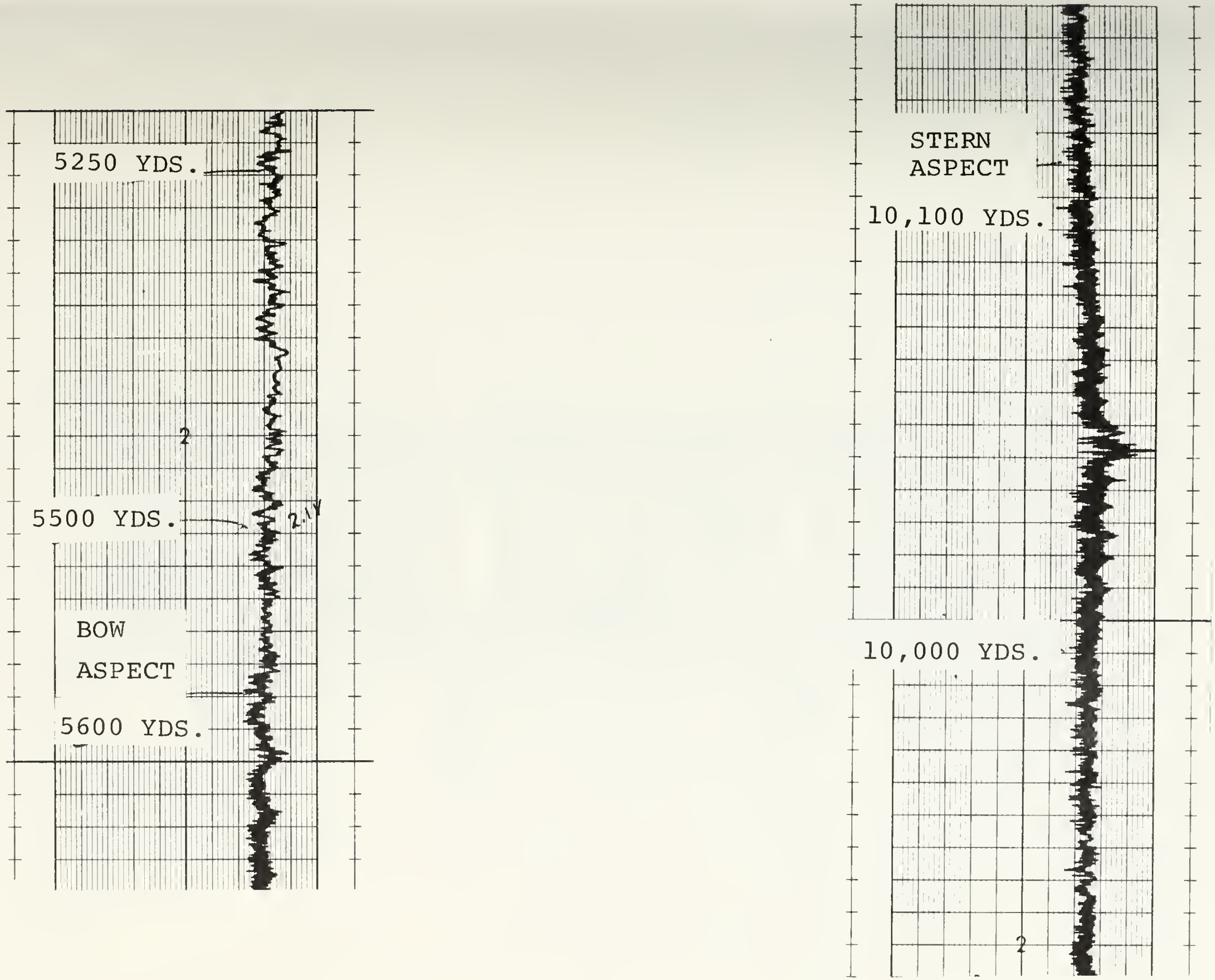

5250 YDS.
2
5500 YDS.
BOW
ASPECT
5600 YDS.
STERN
ASPECT
10,100 YDS.
10,000 YDS.
2

FIGURE 3

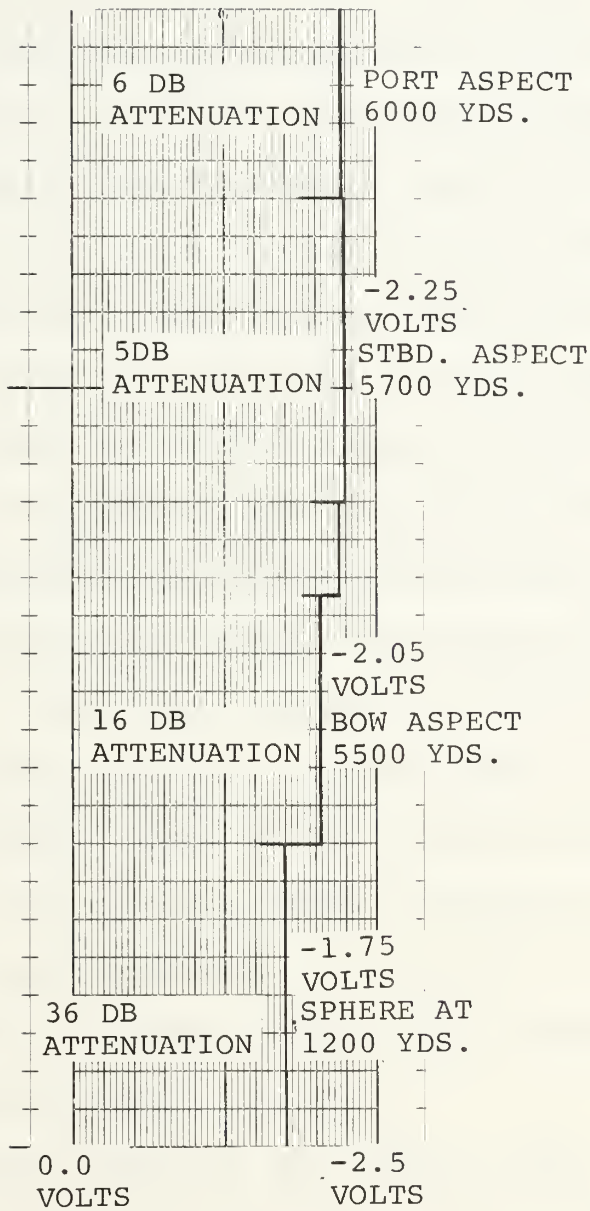

6 DB
ATTENUATION
PORT ASPECT
6000 YDS.
-2.25
VOLTS
5DB
ATTENUATION
STBD. ASPECT
5700 YDS.
-2.05
VOLTS
16 DB
ATTENUATION
BOW ASPECT
5500 YDS.
-1.75
VOLTS
36 DB
ATTENUATION
SPHERE AT
1200 YDS.
0.0
VOLTS
-2.5
VOLTS

FIGURE 4

indicated that for a metallic ship of twice the beam of the ACANIA, an average radar cross section of the bow aspect was on the order of 40 $dBm^2$, 11 $dBm^2$ more than the value determined for the ACANIA. The experiments at NRL were more precise than the results presented here since their data was on a pulse-to-pulse basis and their aspect information was accurate to a fraction of a degree. The AGC voltage data presented in this report is an average value of several pulses, and the averaging mechanism is non linear with respect to power changes. In addition, the experiment conducted to extend the AGC voltage to values higher than those received from the sphere was not conducted on the same day as the tracking exercises due to time constraints. Therefore, the receiver performance might not have been precisely the same on the two days inducing further errors in the data for all cross sections other than the stern aspect. There is no reason to expect a large change in the receiver characteristics in this time, so any resulting error should be small. Based on the results obtained at NRL it would appear that the cross section measured herein is a reasonable value for the ACANIA. This value is all that is required to proceed with the analysis for a suitable amplifier in terms of repeater gain.

From the equation given in the general theory earlier in this section, the electronic gain required in the repeater loop for a 20 dB jam-to-signal ratio, may now be calculated.

$$G_e = 4\pi\, c\sigma/\lambda^2 G_r G_t = 42 \text{ dB} \tag{1}$$

$\sigma$ = 20 $dBm^2$ (stern aspect) $G_t$ = 19 dB

C = 20 dB $\lambda^2$ = -29 $dBm^2$

$G_r$ = 19 dB $4\pi$ = 11 dB

Adding another 3 dB for installation losses and 8 dB to cover the maximum cross section gives a total required gain of 53 dB.

The stern aspect was chosen for use in the above calculations for three reasons. 1. It was calculated directly from the calibration voltage given by the sphere track and is probably more accurate than the data obtained by the signal substitution method. 2. The radar cross section was lower for the stern and use of the minimum cross section reduces the gain and power requirements for the repeater amplifiers. 3. The stern of the ACANIA was the ideal place to mount the repeater antennas since there were very few metallic structures which might reflect transmitted energy at a sufficient amplitude to cause loop oscillations.

# III. ANTENNA ISOLATION

## A. NATURE OF THE PROBLEM

### 1. General Theory

We have seen from the radar cross section experiment that a repeater gain of 53 dB will be required to provide adequate jam-to-signal ratio for the Nike Ajax radar when looking at the stern aspect. Consequently we must have at least 53 dB of isolation between the transmitter and receiver antennas at all frequencies in the pass band in order to avoid positive feedback and possible self destruction of the amplifiers. Utilization of the AN/APG-30 horn type antennas for both transmitting and receiving was deemed an ideal choice since their 19 dB gain helped to reduce both the gain and the peak power requirements of the TWT repeater amplifiers. One of these antennas had also been used in previous interferometer experiments, and the gain as well as pattern information was available for it. The other antenna was similar in design and its pattern and gain were measured in the anechoic chamber while the isolation experiments were being conducted. Isolation experiments were conducted in two phases. Phase one was to simulate free space conditions and was conducted in the anechoic chamber. Phase two was an installation on board the ACANIA.

Rough calculations, prior to antenna pattern measurement, for an antenna spacing of 15 cm. (approximately $5\lambda$) gives only about 40 dB (based on an estimated side lobe level of 10 dB

below isotropic) of isolation between the antenna pair. To gain the necessary isolation the following methods were considered in case the experimental results were of the same order of magnitude. 1. Antenna spacing could be increased laterally as well as in the fore and aft plane to gain 6 dB with each twofold increase in distance. 2. A metal plate with or without absorbing material could be placed in between the antenna pair. 3. Absorbing material could be placed in a cone surrounding each antenna. The 15 cm. dimension happened to be a convenient separation for mounting in the anechoic chamber and would not necessarily be representative of spacing for actual installation on the ACANIA. Therefore experimental results on the ACANIA with greater spacing were expected to be better. A possible source of difficulty with shipboard installation was expected to come from reflections from structures on board. Careful selection of antenna location was expected to help alleviate this difficulty.

## B. EXPERIMENTAL PROCEDURE

### 1. Anechoic Chamber Tests For Isolation

The equipment utilized in the anechoic chamber isolation experiments is shown in figure 5. Signal comparison was the basic method employed to determine the antenna isolation. A Klystron operating at 9.05 GHZ in a cw mode, was connected to the transmitter horn and the receiver connected to the receiver horn. The receiver was operated in an automatic frequency tracking mode. Attenuator No. 1 was adjusted to provide a suitable signal to the Scientific Atlanta receiver. The signal

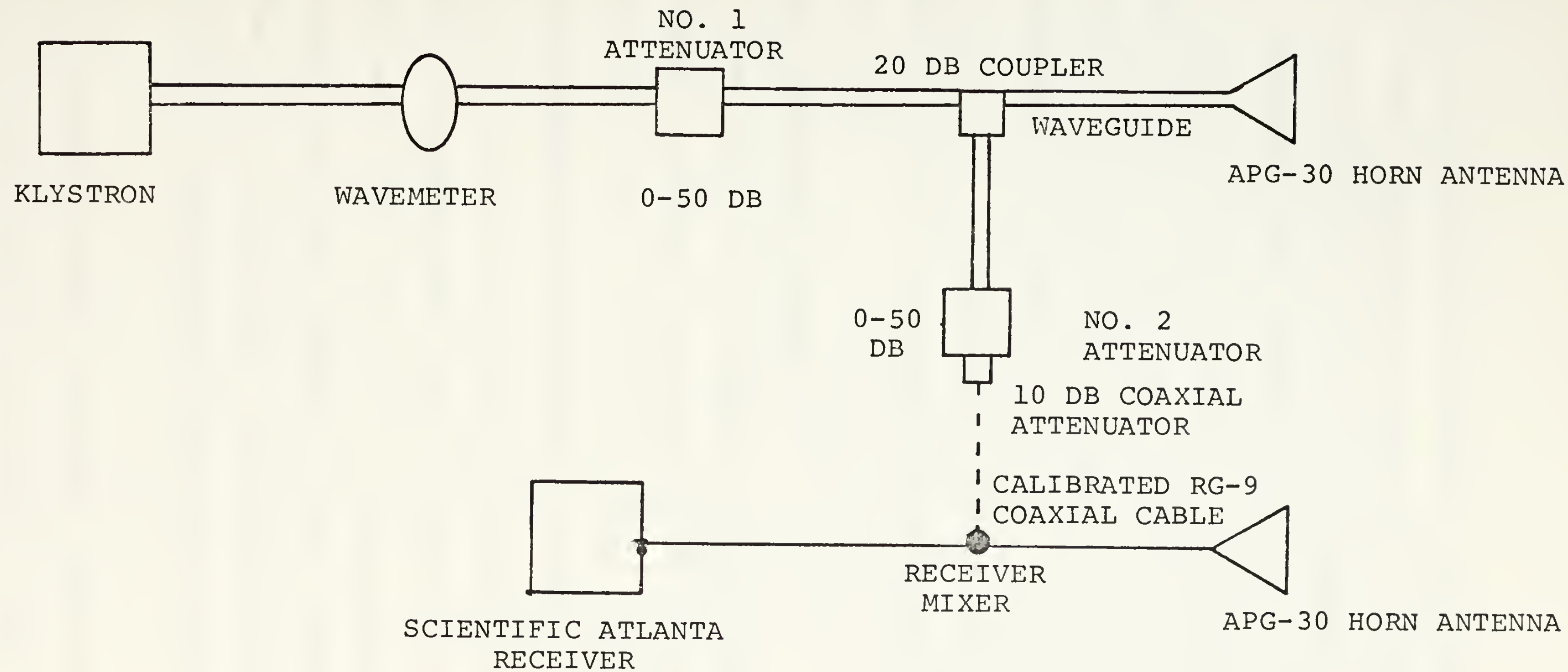

NO. 1
ATTENUATOR
20 DB COUPLER
KLYSTRON
WAVEMETER
0-50 DB
WAVEGUIDE
APG-30 HORN ANTENNA
0-50
DB
NO. 2
ATTENUATOR
10 DB COAXIAL
ATTENUATOR
CALIBRATED RG-9
COAXIAL CABLE
RECEIVER
MIXER
SCIENTIFIC ATLANTA
RECEIVER
APG-30 HORN ANTENNA

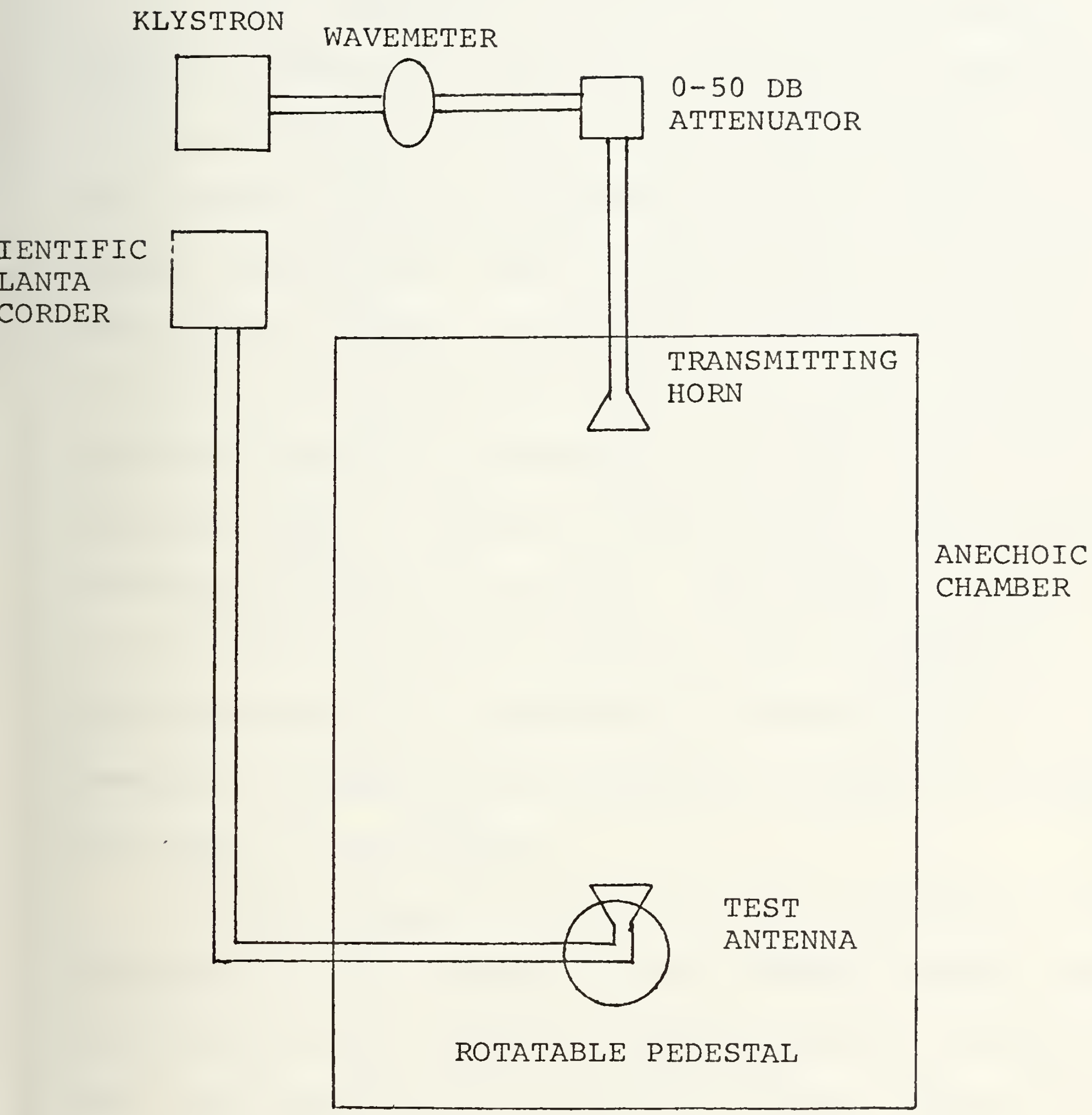
FIGURE 5

strength meter reading was recorded and the receiver was then connected to the 10 dB coaxial attenuator. Variable attenuator No. 2 was then adjusted to give the same signal strength reading as before. The sum of the attenuators in the cross over branch minus the loss in the coaxial cable to the receiving horn yields the antenna isolation. During the conduct of the experiment it was noticed that there were substantial reflections from a rotatable pedestal utilized for antenna pattern measurements. The reflections were minimized by rotating the pedestal for minimum signal indication when the receiver was connected to the receiving horn.

2. <u>APG-30 Antenna Patterns</u>

Antenna pattern measurements were produced in the anechoic chamber to compare the gain of the radar laboratory horn to that of the horn received on loan. Figure 6 shows the experimental apparatus with the distance between the transmitting antenna and the test antenna being much greater than $2D^2/\lambda$ so that the measurements were in the far field. The test antennas were placed on the rotatable pedestal and the system was set up so that 0 degrees on the recorder corresponded to the maximum of the main lobe. Suitable gain was employed on the recorder so that the main lobe peak indicated almost full scale.

The first run was made utilizing a Microline Model 56xl horn, with a calibrated gain of 15.6 dB at 9 GHZ, as the standard for the experiment. Subsequent runs were made with each of the APG-30 horns. All antennas were rotated through



KLYSTRON
WAVEMETER
0-50 DB
ATTENUATOR
IENTIFIC
LANTA
CORDER
TRANSMITTING
HORN
ANECHOIC
CHAMBER
TEST
ANTENNA
ROTATABLE PEDESTAL


FIGURE 6

a full 360 degrees although the plots were cut for convenience in figures 8, 9, and 10, and do not include the full 360 degrees. No significant radiation (greater than -35 dB) was detected beyond the 96 degree position in any case.

3. Shipboard Antenna Installation

Upon completion of the isolation experiments in the anechoic chamber the ACANIA was inspected to determine a suitable location for the antennas and equipment. The stern with antenna looking aft appeared highly favorable since antenna installation there should minimize reflections from ship mounted objects, and the stern radar cross section is relatively low. An ideal location for antenna placement appeared to be on the stanchions located on the 01 level. Equipment could be located in the cabin on the main deck immediately below the antennas. This would require a very short run in terms of low-loss coaxial cable or waveguide. For this brief experiment the equipment was located on the 01 level immediately forward of the antennas to reduce the length of the cable to the antennas.

The equipment utilized for this experiment was almost identical to that employed in the anechoic chamber experiment. One addition was a bandpass filter utilized to protect the open ended mixer of the Scientific Atlanta receiver from possible marine radars operating just above the test frequency of 9 GHZ. The complete equipment diagram is shown in figure 7.

Conduct of the experiment was much the same as in the anechoic chamber tests. The antennas were initially mounted with a separation of 15 cm as before. Following isolation

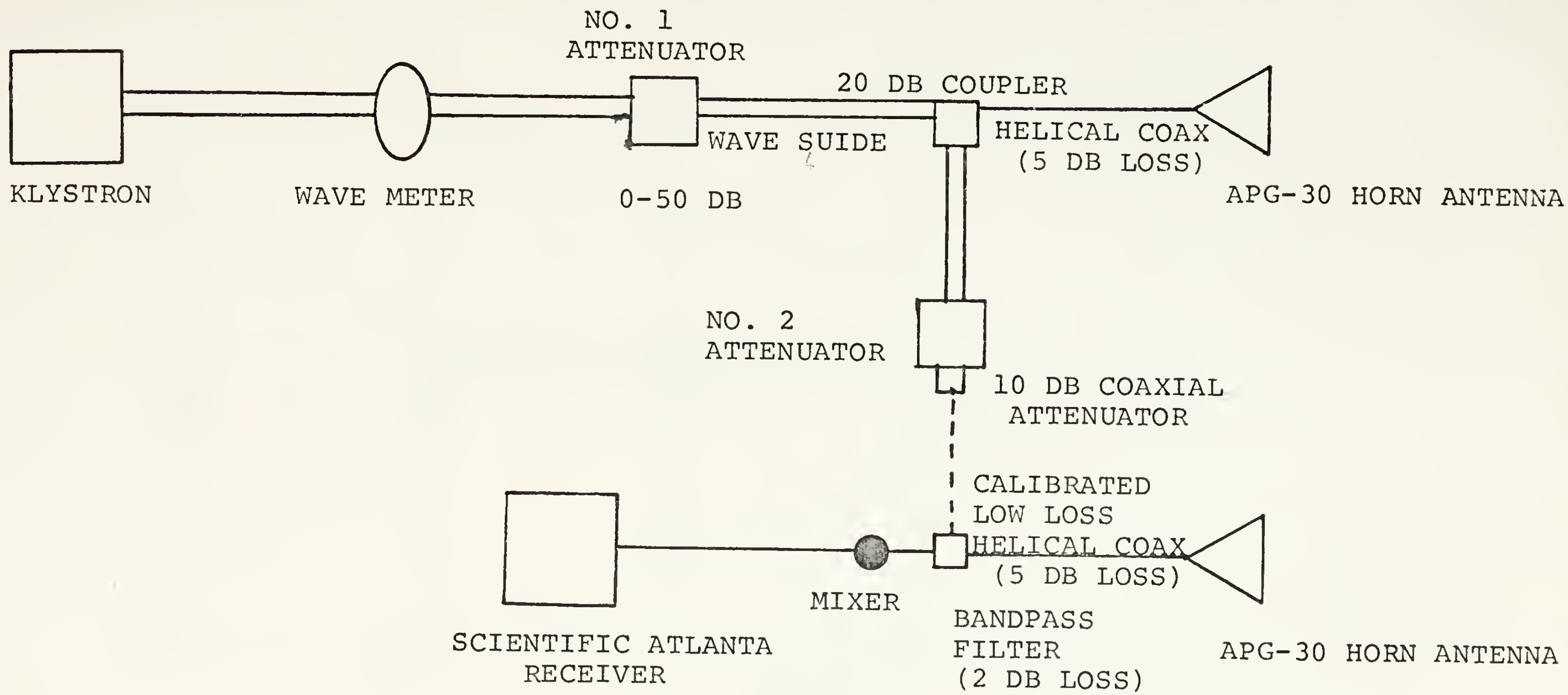

NO. 1
ATTENUATOR
20 DB COUPLER
WAVE SUIDE
HELICAL COAX
(5 DB LOSS)
KLYSTRON
WAVE METER
0-50 DB
APG-30 HORN ANTENNA
NO. 2
ATTENUATOR
10 DB COAXIAL
ATTENUATOR
CALIBRATED
LOW LOSS
HELICAL COAX
(5 DB LOSS)
MIXER
BANDPASS
FILTER
(2 DB LOSS)
SCIENTIFIC ATLANTA
RECEIVER
APG-30 HORN ANTENNA

FIGURE 7

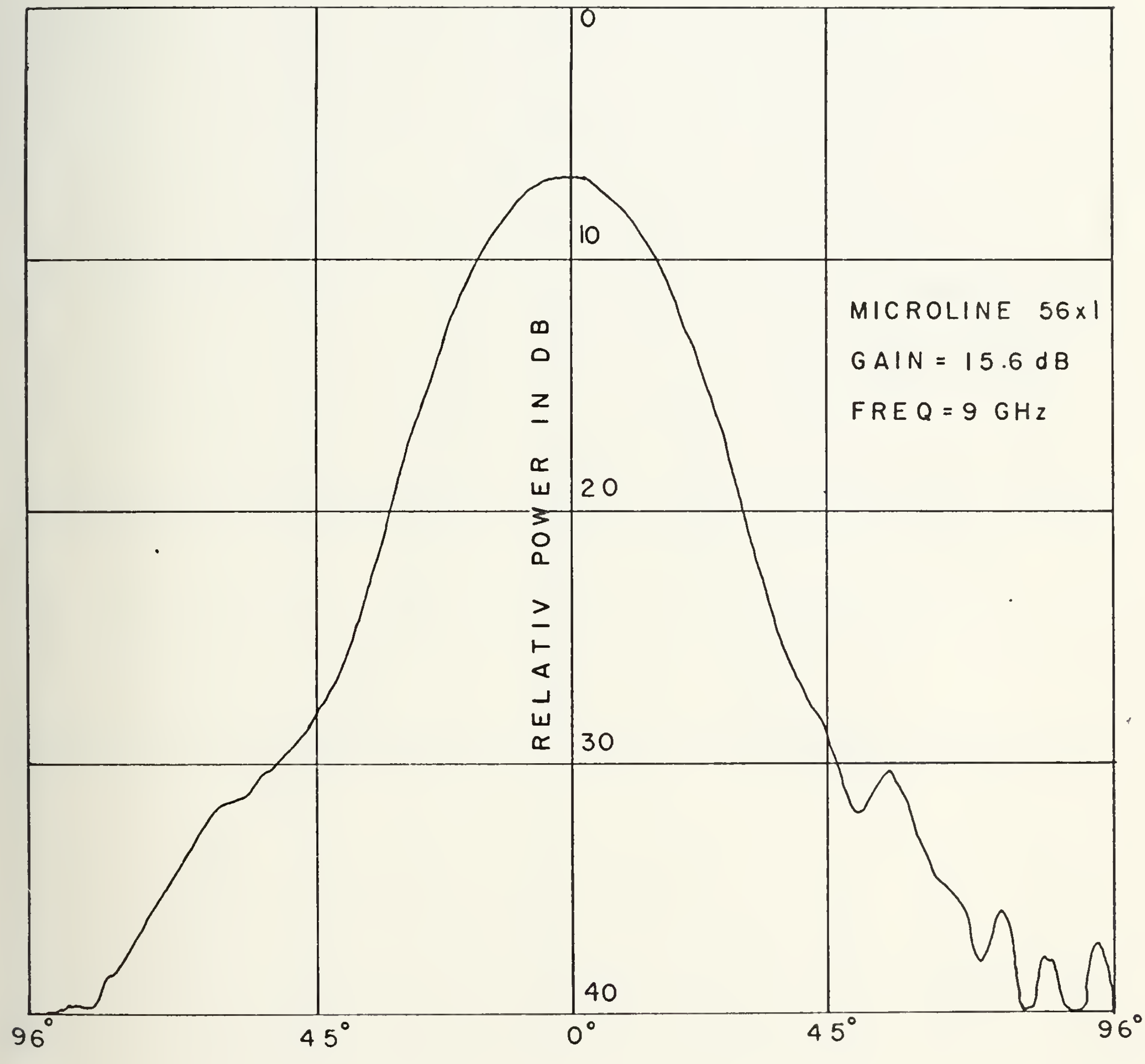

0
10
20
30
40
RELATIV POWER IN DB
MICROLINE 56x1
GAIN = 15.6 dB
FREQ = 9 GHz
96°
45°
0°
45°
96°

FIGURE 8

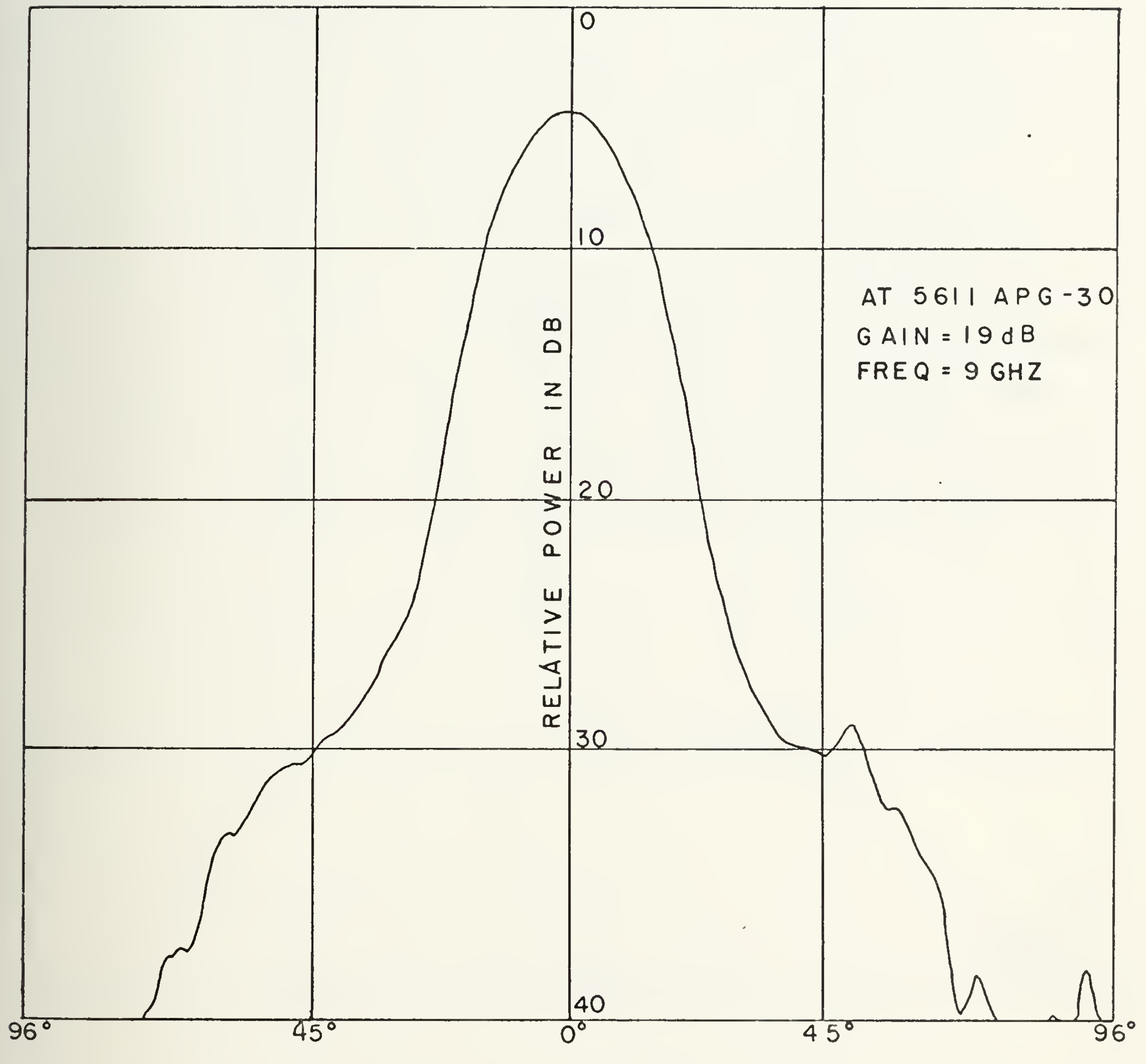
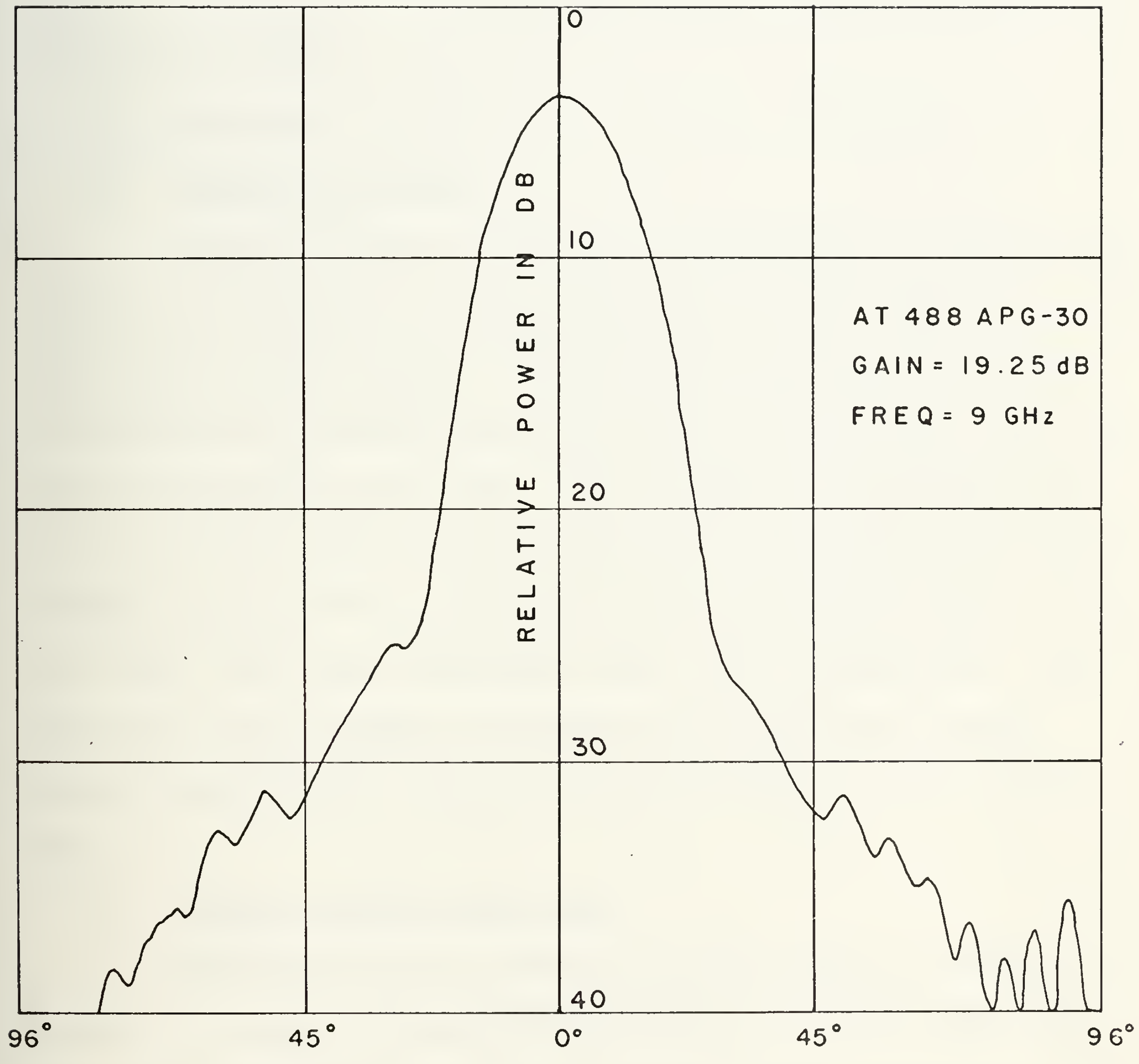

0
10
20
30
40
RELATIVE POWER IN DB
AT 5611 APG-30
GAIN = 19 dB
FREQ = 9 GHZ
96°
45°
0°
45°
96°

FIGURE 9



0
10
20
30
40
RELATIVE POWER IN DB
AT 488 APG-30
GAIN = 19.25 dB
FREQ = 9 GHz
96°
45°
0°
45°
96°


FIGURE 10

measurements at this distance, the receiving horn was placed on the far side of the ship at a distance of 4.5 meters. With favorable results in both locations, the receiving antenna was pointed at various objects on the main deck to determine if any strong reflectors were located just below the plane of the receiving antenna.

## C. PRESENTATION OF DATA

### 1. Antenna Isolation

Antenna isolation results are presented in table I and are self explanatory with the exception of the value for maximum separation on the ACANIA. In this case the reflections from the waves gave readings which varied by $\pm$ 10 dB from the 85 dB value specified in the table. This value is only approximate due to the fact that the No. 2 variable attenuator was reading somewhat greater than 50 dB, in the uncalibrated region. The fact that the signal variations were due to reflections from the waves was confirmed by pointing the receiving antenna skyward and noticing that the received signal became steady again.

### 2. Antenna Patterns and Gain

Measured antenna patterns are contained in figures 8, 9, and 10. Using the manufacturers data available with the Microline Model 56xl horn, its gain was determined to be 15.6 dB at 9 GHZ. From this reference value the gain of the two APG-30 horns was determined to be about 19 dB. Sidelobe levels were at least 34 dB down for both horns at the 90 degree position.

ANTENNA ISOLATION DATA AT 9.05 GHZ

| DISTANCE BETWEEN ANTENNAS | ANECHOIC CHAMBER ISOLATION | SHIPBOARD ISOLATION (dB) |
|---|---|---|
| 15 CM. | -86 dB | -76 dB |
| 30 CM. | -77 dB | Not Measured |
| 5.64 M. | Not Measured | ~85 dB |

NOTE: An additional 5 dB of isolation was obtained by moving the receiving antenna 20 CM. aft of the plane of the transmitting antenna at the 15 CM. spacing.

TABLE I

## D. CONCLUSIONS

Sufficient isolation is present between the horn antennas when located on board the ACANIA to prevent feedback problems in the repeater loops. The values obtained in the experiment were in excess of 75 dB in all cases and only 53 dB of isolation would have been sufficient for a repeater electronic gain of 53 dB. Since the sidelobes of the horn antennas were down 15 dB per horn with respect to an isotropic radiator and separation losses would add about another 35 dB, a rough estimate of the isolation at close distances would be about 65 dB. The values of 75 dB which were measured with a spacing of 15 cm., agree reasonably well with this rough theoretical estimate which is based on far-field equations. The values of 19 dB gain for the horn antennas agree very closely with the values measured by another laboratory for this horn antenna in 1972, namely 19.25 dB. Antenna isolation changes with frequency should not be greater than a few dB since the free-space loss and pattern changes are expected to be on the order of 1 or 2 dB for a frequency change of 3 GHZ.

## IV. AMPLIFIER SELECTION

With the repeater antenna gains known and with the radar cross section of the ACANIA now known, it is possible to calculate the power requirements for the repeater amplifiers at the closest range of interest using the radar range equation. A range of 3 miles is the closest test range possible for any operational evaluation of the system. At that range the jammer power required, based on free-space propagation and assuming negligible loss between transmitter and antenna is given by:

$$P_j = P_t \, G_t \, C \, \sigma \, / \, 4\pi \, G_j \, R^2 = 58 \text{ dBm} = 630 \text{ watts} \qquad (4)$$

Where:

$P_t$ = Transmitter power = 83 dBm

$G_t$ = Gain of transmitter antenna = 40 dB

$C$ = Jammer to signal ratio = 20 dB

$\sigma$ = Stern cross section of ACANIA = 20 $dBm^2$

$G_j$ = Gain of jammer antenna = 19 dB

$R^2$ = Range to ACANIA = 74.7 dB or 3 miles

The above calculation gives the jammer power required to cover the average cross section. An additional 8 dB would be required to give a 20 dB jam-to-signal ratio for the peak cross section value of 28 $dBm^2$, or 3980 watts at the 3 mile range. The power calculations were based on the radar cross section measured at a range of 10,100 yards. The effective cross section at 3 miles may be either larger or smaller due to the

different geometry. Thus the actual power output required at 3 miles may be more or less than that computed above.

One system which would be a good candidate for the repeater amplifier is the amplifier section of a surplus deception repeater. The peak power output is 1000 watts, and 70 dB of gain is available. If we are willing to accept a jam-to-signal ratio reduction of 8 dB, or a net J/S of 12 dB on the peak cross section, then the output power of 1000 watts is sufficient for concept verification at a range of 3 miles. Amplifier saturation should be avoided if the repeater signal strength is to vary realistically with range. In order to prevent amplifier saturation at the minimum range for a 1000 watt amplifier, the electronic gain must be reduced 6 dB to reduce the amplifier output from 3980 to 1000 watts.

Another method could be used to prevent amplifier saturation. Since with a 200 kilowatt radar power output the signal-to-noise ratio at this range is very, very large, the radar power output could be reduced to prevent jammer saturation. One kilowatt jammer output should then be more than adequate. The electronic gain may be easily reduced by inserting a variable attenuator between amplifier stages. Use of the surplus repeater amplifier involves obtaining a 115/205 volt, 3 phase, 400 Hz. power supply. Additionally the programmer logic circuits must be modified.

Commercial sources of TWT's might also be considered on a loan or rental basis. Two Hewlett Packard 495-A TWT amplifiers are available at NPS as low-level drivers, supplying a 1 watt output with 30 dB of gain. They also have provisions for amplitude modulation. Several high-power TWT's supplying

one kilowatt of power and 40 dB of gain are available as off-the-shelf items from various manufacturers.

With the peak power requirements of 1000 watts at a range of 3 miles and with a repeater gain of 53 dB required, the repeater amplifiers should consist of two stages. Any desired modulation could be supplied at the low-level stage or between stages using the second stage as a linear amplifier. When choosing a specific amplifier combination, consideration should be given to the fact that only 115 volts AC single phase power and 12, 24, and 36 volts DC are available on board the ACANIA.

## V. SUMMARY

The measured average cross section of 20 $dBm^2$ for the stern aspect of the ACANIA requires an amplifier gain of 42 dB for a jam-to-signal ratio of 20 dB, utilizing the 19 dB gain APG-30 horn antennas. If amplitude cross section variations are taken into account, and installation losses are considered, the required amplifier gain becomes 53 dB. Utilizing an available one kilowatt amplifier, the gain must be limited to 47 dB to prevent saturation at the minimum range of 3 miles. This would result in a reduction in jam-to-signal ratio to 12 dB at the cross section peaks, but would give a 20 dB ratio for the average cross section value of 20 $dBm^2$.

Measurements indicate that an isolation of 75 dB can readily be obtained between the AN/APG-30 horn antennas. This provides an ample margin of safety.

The one kilowatt surplus deception repeater mentioned earlier meets the amplifier requirements and with suitable modification could be utilized in an operational evaluation of the interferometer concept at this facility.

LIST OF REFERENCES

1. Skolnik, M. I., Introduction to Radar Systems, p. 184-185, McGraw-Hill, 1962.

2. Boyd, J. A., Harris, D. B., Welch, H. W., Jr., Electronic Counter-measures, U. S. Army Signal Corps, 1961.

3. Skolnik, M. I. (editor), Radar Handbook, p. 27-20 and 27-21, McGraw-Hill, 1962.

INITIAL DISTRIBUTION LIST

| | | No. Copies |
|---|---|---|
| 1. | Defense Documentation Center<br>Cameron Station<br>Alexandria, Virginia 22314 | 2 |
| 2. | Library, Code 0212<br>Naval Postgraduate School<br>Monterey, California 93940 | 2 |
| 3. | Department Chairman, Code 52<br>Department of Electrical Engineering<br>Naval Postgraduate School<br>Monterey, California 93940 | 2 |
| 4. | Department Chairman, Code 57<br>Department of Aeronautical Engineering<br>Naval Postgraduate School<br>Monterey, California 93940 | 2 |
| 5. | Mr. Stanley J. Gontarek, Code 53362A<br>Naval Air Systems Command<br>Navy Department<br>Arlington, Virginia 20360 | 1 |
| 6. | Mr. Bernard J. Panella, PME 107-2A<br>Naval Electronic Systems Command<br>Navy Department<br>Arlington, Virginia 20360 | 1 |
| 7. | Mr. James M. Burn, Jr., Code 5731<br>Naval Research Laboratory<br>Washington, DC 20375 | 1 |
| 8. | Mr. William V. Moffat<br>Radcon, Inc.<br>Box 1921<br>Monterey, California 93940 | 1 |
| 9. | Professor David B. Hoisington<br>Department of Electrical Engineering<br>Naval Postgraduate School<br>Monterey, California 93940 | 1 |
| 10. | LT Michael J. Duncan<br>Assistant Strike Operations<br>USS ENTERPRISE (CVAN 65)<br>FPO San Francisco 96601 | 1 |
| 11. | LT Ronald Higdon<br>Department of Aeronautical Engineering<br>Naval Postgraduate School<br>Monterey, California 93940 | 1 |